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National Park stewardship and 'vital signs' monitoring: a case study from Channel Islands National Park, California

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ABSTRACT

1. Place-based conservation strategies require that stewards know and understand the targeted ecosystems, restore impaired resources, protect the ecosystems, and connect people wholeheartedly to the places. Knowledge of ecosystem structure and functioning is the cornerstone of stewardship.
2. This paper describes the design, implementation, and application of an ecological monitoring program in Channel Islands National Park, California, USA. Experience from this program showed that monitoring ecological 'vital signs' was a quick, sure, and inexpensive way to discover and track ecosystem dynamics.
3. Monitoring ecological 'vital signs' determined status and trends of ecosystem integrity and established limits of normal variation of key ecosystem features. It also provided early warnings of situations that required intervention and helped frame research questions to determine chains of cause and consequence.
4. The strong influence and probabilistic nature of biological interactions in ecosystems precluded effective use of deterministic modeling to accurately predict ecosystem behavior. Therefore, ongoing monitoring was required to reliably increase knowledge of system dynamics. The U. S. National Park Service has begun to identify and monitor the ecological 'vital signs' in 32 networks of 270 parks.

KEY WORDS: monitoring; ecology; protected area; stewardship; vital signs
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INTRODUCTION

This paper describes a design process for developing ecological monitoring programs using a medical metaphor for 'vital signs.' Design and implementation of a monitoring program from 1980 through 2003 provides an example of how that process was used at Channel Islands National Park, California. Finally, the paper presents some results of this monitoring and shows how those results affected conservation issues in and around the park.

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Place-based conservation requires that stewards know and understand the ecosystems they conserve. Stewards need to protect the places and mitigate threats to these places. They must also restore impaired elements of those ecosystems, and connect people to the places to sustain support for conservation. Understanding ecosystems is 'first among equals' of these four pillars of placed-based stewardship: know, restore, protect and connect.

Monitoring long-term dynamics of critical ecosystem elements is a direct way to learn how ecosystems behave and how the various elements interact and influence one another, thereby increasing understanding. The term 'vital signs' is used here to connote a small suite of basic environmental measures, including biologic (e.g., giant kelp abundance and distribution), physical (e.g., sea temperature), and chemical (e.g., pH) elements and processes, that represent the entire array of such features in an ecosystem, and that reflect temporal and spatial changes in ecosystem structure and function. These kinds of ecosystem features are variously termed focal, flagship, keystone, umbrella, or indicators (Simberloff, 1998; Zacharias and Roff, 2001). The term 'vital signs' is used here to indicate that a small selection of a very large array of potential ecosystem features was made in an initial attempt to discover a tractable number of critical ecosystem features that would represent system conditions, corresponding to the medical selection of a few critical measures used to assess basic human health condition.

METHODS: DESIGN PROCESS AND STEP-DOWN PLAN

Identifying and measuring 'vital signs' of ecosystems is a difficult and complex endeavor involving many discrete but interdependent activities or projects (Davis 1989, 1993). This complexity, and the magnitude of the work, can overwhelm stewards faced with conserving endangered species, fending off invasive alien species, and mitigating pollution, while enduring severe fiscal and personnel constraints. Phenicie and Lyons (1973) provided a generic graphic framework for organizing such activities into a logical, tiered, step-down plan and diagram that clearly displays relationships among all planned activities. A four-step plan at Channel Islands National Park facilitated explaining the need for a 'vital signs' monitoring program and helped to gain support and collaboration. The plan also allowed all collaborators to see easily how their contributions related to the whole effort.

The first step in the plan was to set program goals (Figure 1). The line below the program goals on the diagram indicated all of the actions—*and only those actions*—required to achieve the goals on the line above it. Actions on the second line became the goals for the next step down, indicated on the third line. This step-down process continued to divide large complex tasks or programs into feasible actions until the actions on the bottom line were sufficiently simple to define a single research project or monitoring protocol. If the process were continued further to detail portions of monitoring protocols, such as individual sampling procedures, excessive detail obscured the relationships of actions and goals for the entire program, and the plan lost much of its clarity. In this case, the next three steps were to develop a conceptual ecosystem model, to develop monitoring protocols for selected ecosystem 'vital signs,' and to implement monitoring.

The step-down diagram helped reduce the overwhelming tasks of conceptualizing all of the interactive parts of a large, complex ecosystem and designing and implementing a strategy to monitor it into feasible tasks and fundable projects. The process of deconstructing the overall task into smaller related activities greatly aided communication among collaborators and helped overcome institutional inertia. It also provided a record for future generations of stewards to see how and why particular parameters were initially selected as 'vital signs,' and to better inform future decisions to adapt monitoring to changing conditions and knowledge.

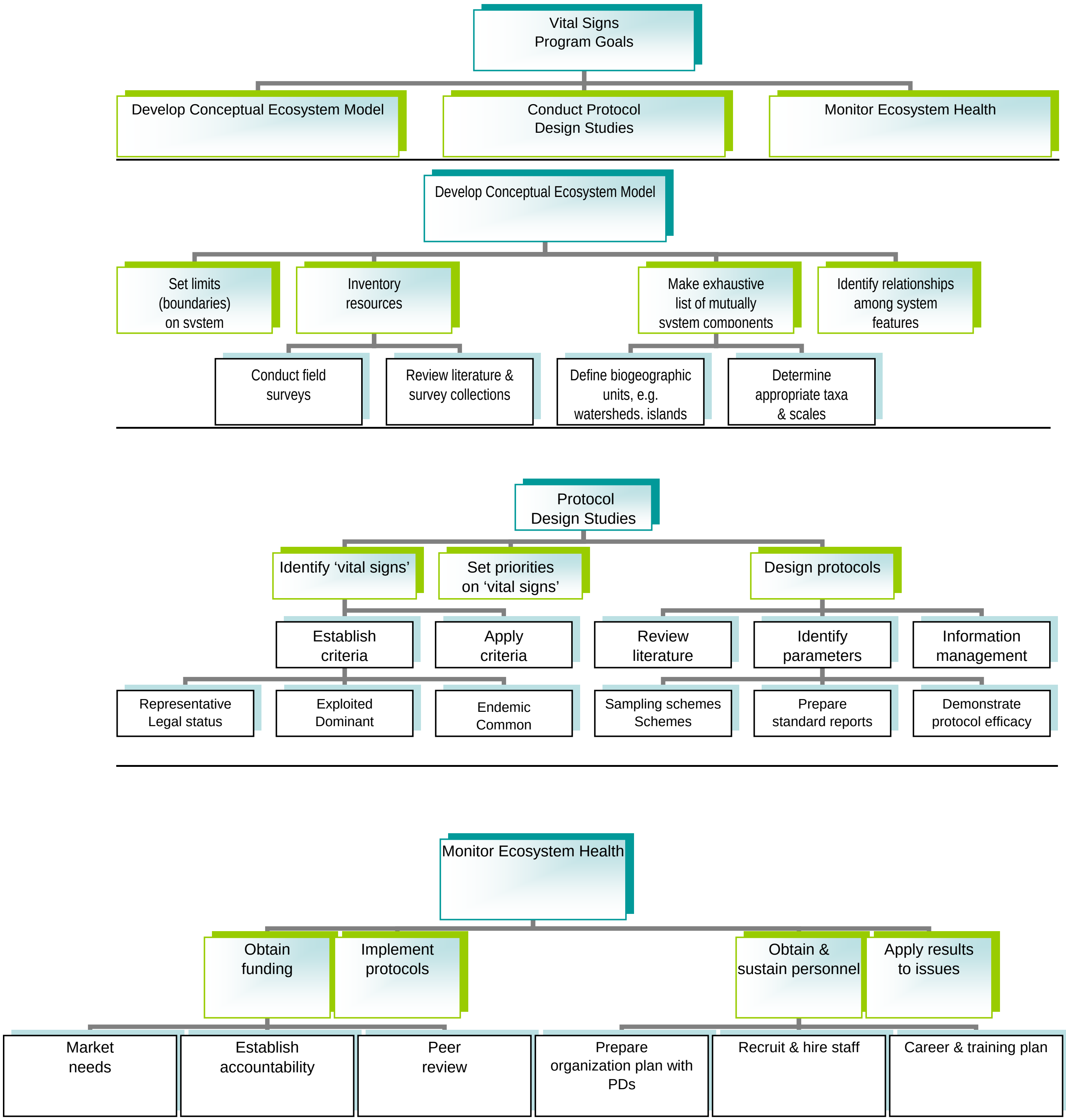

Figure 1. Step-down diagram for design and implementation of a 'vital signs' monitoring programme at Channel Islands National Park, California

CHANNEL ISLANDS NATIONAL PARK CASE STUDY

National parks in the United States were established to conserve unimpaired scenery, natural and historic objects, and biodiversity in parks, and to provide for their enjoyment now and in the future. Channel Islands National Park was established in 1980 to preserve self-sustaining examples of coastal ecosystems in southern California. The region's first conservation designation came in 1938, when President Franklin D. Roosevelt proclaimed Channel Islands National Monument to protect the islands of Santa Barbara and Anacapa. Since then, several governmental bodies have conferred a variety of conservation designations on the five California Channel Islands and the sea around them that comprise the park (Table 1). The National Park Service instituted a 'vital signs' monitoring program to inform, guide, and evaluate stewardship of the park. Research designed to determine ecological chains of cause and consequence was considered beyond the scope of such a monitoring program.

The Channel Islands ecological setting, including biological resources (populations and communities), environmental forces (climate and ocean currents), land forms (islands and ocean basins), and management issues, and the park's legal purpose combined to determine the function–and thereby the structure–of the monitoring program. Major issues that focused this monitoring program included:

- unsustainable fishing, destructive grazing, and disturbances by visitors;
- habitat fragmentation, including loss of nearby mainland habitat and island erosion;
- air and water pollution and loss of fog-drip precipitation; and
- invasive alien species, such as the seaweeds *Undaria pinnatifida, Sargassum muticum*, and *Caulerpa taxifolia*, and feral pigs, sheep, and rabbits.

Monitoring Programme Goals

The generic step-down plan above was used to develop a 'vital signs' monitoring program for Channel Islands National Park (Davis *et al*., 1994). The program's four goals, established in the first step of the plan were to:

1. Determine present and future ecosystem integrity, a multidimensional property of ecological systems that indicates the nature of their organization—structure composition, and processes (Parrish et al., 2003).
2. Establish empirically normal limits of variation.
3. Provide early diagnosis of abnormal conditions.
4. Identify potential agents of abnormal change.

Table 1. Conservation designations of the California Channel Islands in and adjacent to Channel Islands National Park.

- International Biosphere Reserve (designates special recognition for conservation and education)
- National Marine Sanctuary (multiple use management & protects seabed and air space)
- National Oil and Gas Sanctuary (prohibits petroleum exploration and exploitation)
- National Park (preserves island and marine ecosystems)
- State Marine Reserves—10 (prohibit fishing)
- State Marine Conservation Areas—2 (regulate fishing)
- State Area of Special Biological Significance (ASBS) (regulates water quality)
    - Santa Rosa Island ASBS
    - Santa Cruz Island ASBS
- State Area of Environmental Concern (regulates land use)
- University of California Santa Cruz Island Nature Reserve (identifies research site)
- The Nature Conservancy, Santa Cruz Island Project (preserves island biodiversity)

Table 2. Summary of major elements of the Channel Islands National Park, California conceptual ecological system model used to design a 'vital signs' monitoring program in 1980.

Mediterranean-type ecological system	
	Warm, dry summers (10-35 ºC, trace precipitation)
	Cool moist winters (0-20 ºC, 30-40 cm precipitation)
	Spring and summer coastal fog
	Fall and winter continental winds—Santa Annas
Two biogeographic provinces	
	Warm-temperate Californian
	Cool-temperate Oregonian
	Transition Zone
Islands	
	Large (20,000-22,000 ha)
	Medium (5,000 ha)
	Small (260-300 ha)
	Perennial streams
	Diverse shoreline—sea cliffs, beaches, sand dunes, and sea caves
Ocean	
	Persistent oceanic upwelling and strong south-flowing California Current nearby
	Confluence of warm (14-22 ºC) and cool (10-16 ºC) inshore ocean currents
	El Niño-La Niña and decadal climatic oscillations
Biological features	
	Island plant communities—pine forests, oak woodland, coastal scrub, grassland
	Island plant populations—endangered, threatened, and endemic species
	Island animals—mammals, herpetofauna, birds, and invertebrates
	Lagoon and estuarine communities
	Sand beach community
	Rocky intertidal communities
	Kelp forests—algae, invertebrates, and fishes
Human influences	
	Regional pollution, e.g., DDT, PCBs, ozone
	Grazing
	Fishing
	Offshore petroleum extraction
	Invasive alien species
	Park visitors

After setting these program goals, the next step was to create a shared conceptual model of the park that all of the collaborators who helped design the program understood and accepted. It included descriptions of the park's biological features, environmental setting, land and sea forms, and threats to the park's ecological integrity, e.g., alien species, unsustainable uses, and pollution. The following description of the park and its environs, summarized in Table 2, constitutes this conceptual model.

Site description/conceptual model

Channel Islands National Park comprises five islands and 50,300 ha of surrounding waters within 1.9 km of each island. The islands lie 20-110 km off the southern California coast between Santa Barbara and Los Angeles (Figure 2.). Some the world's largest kelp forests surround the islands. The region enjoys a mild Mediterranean climate with warm, dry summers and cool, moist winters. These islands and surrounding waters bridge two biogeographical provinces, the warm-temperate Californian and cool-temperate Oregonian (Hedgepeth, 1957; Briggs, 1974), which include the biologic diversity of 1,500 km of the North American west coast. Nearly 1,000 species of marine fish, invertebrates, and algae occur in extensive kelp forests of *Macrocystis pyrifera* surrounding the islands (Davis *et al*., 1997).

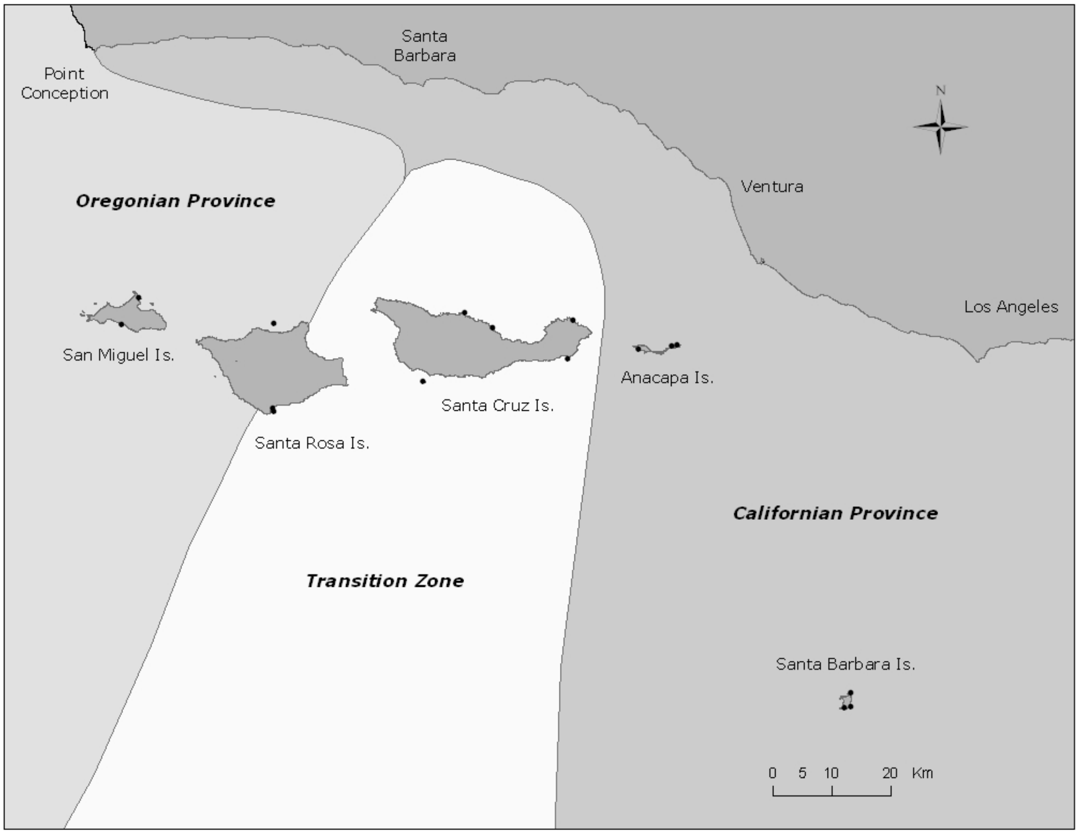

Figure 2. Channel islands National Park. ▲: kelp forest monitoring sites

The nearby confluence of ocean currents and a persistent upwelling zone off nearby Point Conception bring nutrients up from the dark seabed into well lighted surface waters, providing the basis for exceptionally high productivity. Northern elephant seals (*Mirounga angustirostris*), sea lions (*Zalophus* spp.), fur seals (*Callorhinus* spp.), harbor seals (*Phoca* sp.), Cassin's auklets (*Ptychoramphus aleuticus*), Xantus' murrelets (*Endomychura hypolencia*), cormorants (*Phalacrocorax* spp.), pigeon guillemots (*Cepphus columba*), petrels (*Oceanodroma* spp.), gulls (*Larus* spp.), and brown pelicans (*Pelicanus occidentalis*) breed and raise their young on these islands, with nearby abundant food and safe from disturbance on the 240 km shoreline of sand beaches, rocky tide pools, and shear cliffs that ring the islands. Twenty-six kinds of cetaceans occur around the islands, including pacific whitesided dolphins (*Lagenorhynchus obliquidens*), humpback whales (*Megaptera novaengliae*), Orcas (*Orcinus orca*), and blue whales (*Balaenoptera musculus*).

This mild Mediterranean climate, with its extensive coastal fog, supports a wide array of plant and animal communities on the islands. Long isolation protected island species from competition with large diverse conspecific mainland populations and from destruction by modern human activities. Endemic island oak (*Quercus tomentella*), ironwood (*Lyonothamnus floribundus*), torrey pine (*Pinus torreyana*), and other trees rise above grasslands interspersed with fields of coastal sage (*Artemisia californica* and *Salvia* spp.) and bush lupine (*Lupinus arboreus*). Riparian corridors of more than a dozen perennial streams dissect coastal marine terraces. Small populations and limited island habitats relegate many species to rare and endangered status, and accelerate evolution of unique life forms. Nearly 10% of island plants are endemic, while fossils record the past presence of giant mice, flightless ducks, and mammoths.

Numerous archeological sites on the islands reveal human habitation spanning more than 10,000 years. Today, nearly 18 million people live within 300 km of the park. These people bring worldwide demands and cultural values for coastal resources from more than 170 human cultures. Ocean waters both facilitate and limit public access to the islands. Each year, 100,000 scuba divers explore island reefs and kelp forests. Boaters find shelter in nearly 100 secluded anchorages in the park. Campgrounds provide visitors extended access to the islands.

Air and water pollution from nearby metropolitan and industrial developments threaten island ecosystems. Sheep and cattle ranching on the islands introduced alien species, greatly accelerated erosion, and reduced the height of vegetation from meters to centimeters. The reduced height of vegetation further dried the already near-desert islands by virtually eliminating the capacity of tall shrubs to capture moisture from the marine fog blown across the islands by prevailing winds. Park waters once yielded many thousands of tons of fish, shellfish, and kelp annually to commercial and recreational fishers, producing some 20% of California's nearshore landings from only 3% of the state's coastal waters. Recent collapses of fishery-targeted populations revealed that managed traditionally, neither the fisheries nor the populations were sustainable. All of these human activities interacted to alter native island and ocean communities. Normal dynamics of these systems, exemplified by El Niño and La Niña events, masked human influences and made management uncertain, at best.

Design studies

The tension between research studies and monitoring operations was important to resolve institutionally. Research requires near-constant revision in experimental design and sampling to test new hypotheses, after falsifying the previous ones. Each round of hypothesis testing generally requires new funding and new experimental designs. Monitoring requires long-term commitments to consistent data collection, seeking to understand changes over time, frequently over decades. Constant funding is needed to assure continuation and consistency. To resolve difficulties with maintaining continuous funding and steady direction, the National Park Service defined monitoring as an ongoing field-level park operation, just like routine maintenance of park facilities, rather than as centrally-directed research. Nevertheless, short-term (3-5 year) research studies were used to develop monitoring protocols. A modified Delphi approach (Linstone and Turoff, 1975) was used by experts to identify ‘vital signs’ and to organize them into discrete protocols. Fourteen monitoring protocols were identified for groups of resources such as pinnipeds, sea birds, kelp forest, or terrestrial vegetation (Table 3).

‘Vital signs’ identification

Experts for each protocol further discussed parameters of features to be designated as ‘vital signs’ and appropriate spatial and temporal scales for monitoring. Demographic parameters of selected species of plants, marine invertebrates, fishes, reptiles, birds, and mammals, and measures of vegetation community structure and composition were identified as ‘vital signs’. Specifically they selected measures of abundance, geographic distribution, age structure, reproduction, juvenile recruitment, and growth and mortality rates. Basic environmental parameters, such as sea temperature, precipitation, and meteorological measures were also identified as ‘vital signs’. Collectively, these population and environmental parameters were selected to allow projections of future conditions and to provide early warnings of impending issues. These parameters were also selected because they integrate responses to a broad variety of normal environmental and human-induced stresses, including both subtle chronic stress and critical acute events. These parameters also directly indicated effects of remedial actions, such as removal of alien species or mitigation of visitor disturbance.

Table 3. Monitoring protocols developed for the Channel Islands National Park 'vital signs' monitoring program listed in priority order as determined in the step-down plan process

Protocol	**Reference**	**Principal Investigator's Affiliation**
Pinnipeds	DeMaster, *et al*. 1984	National Marine Fisheries Service
Information Management	Dye 2002	Private Consultant
Tide Pools	Richards and Davis 1988	Private Consultant
Sea Birds	Lewis *et al*. 1988	University of California
Kelp Forests	Davis 1988; Davis *et al*. 1997	National Park Service with California Department of Fish & Game
Land Birds	Van Riper *et al*. 1988	National Park Service
Island Plants & Vegetation	Halvorson *et al*. 1988	National Park Service
Island Invertebrates	Fellers and Drost 1988a	National Park Service
Island Reptiles & Amphibians	Fellers and Drost 1988b	National Park Service
Island Mammals	Fellers *et al*. 1988	National Park Service
Park Visitors	Davis and Nielsen 1988	National Park Service
Fisheries	Forcucci and Davis 1988	National Park Service
Weather	Halvorson and Doyle 1988	National Park Service
Beaches and Lagoons	Dugan *et al*. 1990	University of California

Table 4. Criteria used to select species, or other taxa, as ecological 'vital signs' for monitoring in Channel Islands National Park, California, and to assure selection of a representative sample of all species and taxa in park ecosystems.

1. Common species that dominate community structure
2. Legal status, e.g., designated endangered species
3. Park or island endemic species
4. Exploited species
5. Alien species (non-native)
6. Heroic, charismatic species with current human constituencies

Design studies were conducted for each protocol. Each design study addressed the same five tasks. They were to: 1) confirm or modify selection of 'vital signs' (species or environmental factors), 2) develop sampling techniques, 3) test analytical approaches, 4) develop report formats and content, and 5) demonstrate the efficacy of the recommended monitoring protocol by field testing all aspects of the protocol for at least two years.

Because the scales of ecological measurements significantly influence understanding of ecosystem dynamics (Dayton and Tegner, 1984), 'vital signs' monitoring employed a variety of sampling schemes to meet program goals, e.g., island plants were sampled at three spatial scales: populations, communities, and landscapes, at one, one, and five year intervals, respectively.

It is important to recognize that the 'vital signs' design process is iterative, and to recognize that limitations of current ecological expertise approximate a 17th Century level of medical knowledge. Consequently, one should acknowledge that the goal of a 'vital signs' design process is to identify and define a reasonable starting point, rather than seek a final solution at the outset. It is also important to recognize that this program was designed to further the understanding of ecosystems, and not as a regulatory tool defining threshold values that would trigger predetermined management responses to changes in environmental conditions.

Selecting biological features to serve as ‘vital signs’ was one of the most difficult tasks. Experts applied six selection criteria to existing biologic inventories (Table 4). Where existing inventories were inadequate to offer a range of selections, field surveys were conducted. Field surveys were needed for terrestrial invertebrates, amphibians, and reptiles. The purposes of these criteria were to assure selection of a representative sample of all features in the ecosystem, and to assure that the selected ‘vital signs’ incorporated a broad array of ecological roles. Additionally, the monitoring program had to account for all endemic, exploited, and alien species, as well as all taxa with special legal status, e.g., endangered species. Common sense indicated selecting ‘heroic’, charismatic species with human constituencies, i.e., species about which the public already cared and empathized.

Sampling strategies

Using the kelp forest monitoring protocol as an example (Davis *et al.,* 1997), site selection for sampling began with existing species inventories, including distribution maps of giant kelp (*Macrocystis pyrifera*) surface canopy. Historical ranges and phenology dictated initial sampling locations and seasons, e.g., where and when rookeries were active. Field surveys during the design studies confirmed those data or modified them. Monitoring locations were established to provide replicate sites representing a range of conditions or along environmental gradients. Kelp forests in the park occur along two biogeographic and physical gradients. Biogeographically, kelp forest assemblages of algae, invertebrates, and fishes in the cold, nutrient-rich waters of the western islands in the Oregonian zone (stretching north to Alaska) were quite distinct from those in the warm waters around the southeastern islands in the Californian zone (extending southward to the middle of Baja California in Mexico). A third assemblage occupies a transition zone between these two extremes. Physically, kelp forests north of the islands are exposed to winter storm waves from the Gulf of Alaska, while those on the southern shores are protected from winter storms. The islands’ south coast kelp forests are exposed to large summer swells generated from winter storms in the Southern Hemisphere and nourished by seasonal upwelling from adjacent oceanic basins. These different physical settings created six discrete kelp forest zones (three biogeographic zones by two exposure zones). At least two monitoring sites were established in each of the six zones. Because sustaining fishing was such a major issue in the park, additional monitoring sites were selected to compare fished with unfished kelp forests. Sixteen kelp forest monitoring sites were established (Davis *et al.,* 1997).

Fixed monitoring sites were selected using stratified random approaches, with stratification based on conservative, stable, physical features as described above for kelp forests. Fixed sites were established because the primary purpose of the program was to measure change over time, not to make population estimates for the entire park. Fixed ecological monitoring sites were established so that changes in parameters would reflect changes over time and not be confounded by within-site variation. Therefore, each site was physically and electronically marked to assure that sampling occurred in precisely the same places every year.

Sampling techniques were generally species and place-dependent, so otherwise standard techniques needed to be adapted to particular sites and situations. Resolution of these matters was a main function of the protocol design studies. Goals for accuracy and precision of monitoring at Channel Islands National Park were set *a priori* by park managers to detect 40% changes in mean values, with α=0.05 and β=0.20. A false positive error (α) means the probability of erroneously reporting that a parameter changed when it really did not, and a false negative error (β) means the probability of not detecting a change when it occurred. Probabilities were typically set at 5% and 20%, respectively, because filing a false report was considered more serious than failing to detect a change.

People who use the monitoring information made these guidelines explicit, based largely on concerns about cost and accountability for the nation's heritage. They determined that the park could not afford to detect 5-10% changes and could not afford ***not to*** detect 50% losses of critical resources, such as endemic species. This 40% goal was a pragmatic compromise between cost and risk. It was an attempt, in an adaptive management scheme, to balance scientific credibility and practicality that could be tested and modified in response to experience. These same parameters of accuracy and precision also established important standards for decadal monitoring protocol performance evaluations.

A variety of sampling techniques was required for the array of biological features in the park selected as 'vital signs' for monitoring. For example, more than 1,000 species of plants and animals inhabit kelp forests in the park. The expert Delphi group selected 70 of these taxa and three physical environmental features to monitor at the 16 fixed sites (Table 5). Specific goals of the kelp forest monitoring were to detect and describe biological responses to large-scale events, such as El Niño, and to help differentiate the effects of regional pollution from effects of fishing. Abundant (high population densities), ubiquitous, discrete species (non-colonial) such as sea urchins and kelps are relatively easy to count and measure in 1-5 m^2 quadrats placed in a stratified random fashion around a fixed 100-m long transect line. The design study resolved the minimum number of quadrats needed (20) and how large each needed to be (1-5 m^2) to reduce within-site variation and achieve the established statistical goal (to detect 40% changes in mean values) at all sites. Species with lower population densities, especially ones that tended to clump such as abalone and lobster, required larger plot sizes to resolve the same degree of change in abundance. A different sampling strategy based on band-transects (12, 3 m X 20 m) was designed for that purpose.

Another function of design studies was to develop and adapt new technologies to provide the most accurate (closeness to true value), precise (closeness of repeated measurements), and cost-effective techniques. Since colonial species, such as the strawberry anemone (*Corynactis californica*) and bryozoan (*Diaporecia californica*), and algae that literally carpet the sea floor cannot be counted easily as individuals, 1,000 randomly selected points in 50 plots were used to estimate cover as an index of abundance. Recording observations for 15 taxa at 1,000 points at each site was a significant bookkeeping exercise for divers underwater. Scuba was the standard equipment employed by scientists to access kelp forests, but it required extensive, slow and tedious record keeping underwater by chilled divers to record up to 15,000 observations of bottom cover at each site. Using equipment more commonly used in commercial diving that provided air and communications to and from the surface shifted record keeping activities to warm, dry data recorders at the surface who simply recorded observations dictated to them by biologist-divers.

It also increased the speed and accuracy of the sampling. Recording bottom cover and abundance of colonial taxa required an average of seven hours at each site using scuba. Having divers dictate the observations to a person recording on a ship at the sea surface reduced the average sampling time to 90 minutes, a savings of 330 minutes of very expensive bottom time for each site. That was the equivalent of an entire week's diving for a crew of eight each year. Because the surface recorders were unaffected by nitrogen narcosis that may plague divers, data quality was also measurably improved.

Design studies also needed to invent new techniques and to test old, standard ones. Fish have always been difficult to sample with non-lethal means because they are mobile, patchy, and sensitive to observer presence. Most kelp forest fishes are long-lived residents of relatively small areas. Many live 30-70 years in one place, once they settle to the bottom as juveniles. Traditional fishery sampling involves taking fish permanently from the population with fishing gear, which would have serious deleterious effects on long-lived resident populations. Davis and Anderson (1989) discovered that traditional, non-destructive, *in situ* fish population assessments in kelp forests had very low accuracy. The program continued to explore appropriate techniques for sampling fishes (Davis *et al*., 1996a). Currently, fixed transects and the REEF roving-diver technique are employed for comparison (Bohnsack, 1996; Pattengill and Semmens, 2003).

Table 5. Summary of taxa and environmental features selected as 'vital signs' of kelp forest ecosystems in Channel Islands National Park, California.

Algae			
Macrocystis pyrifera	giant kelp	Corallinaceae	articulated coralline algae
Laminaria farlowii	oar weed	Corallinaceae	encrusting coralline algae
Eisenia arborea	southern sea palm	*Gelidium* sp.	agar weed
Pterygophora californica	California sea palm	*Gigartina* sp.	sea tongue
Desmarestia sp.	acid weed	Rhodophyta	other red algae
Cystoseira sp.	bladder chain kelp	Chlorophyta	green algae
Phaeophyta	other brown algae	Plantae	miscellaneous plants (e.g. diatoms, *Phyllospadix*)
Invertebrates			
Tethya aurantia	orange puffball sponge	*Kelletia kelletii*	Kellet's whelk
Porifera	other sponges	*Lithopoma gibberosum*	red top snail
Corynactis californica	strawberry anemone	*Lithopoma undosa*	wavy top snail
Urticina lofotensis	white-spotted rose anemone	*Megathura crenulata*	giant keyhole limpet
Astrangia lajollaensis	La Jolla cup coral	*Serpulorbis squamigerus*	scaled tube shell
Balanophyllia elegans	orange cup coral	*Diaporecia californica*	southern staghorn bryozoan
Lophogorgia chilensis	red gorgonian	Ectoprocta	other bryozoans
Muricea californica	California golden gorgonian	*Asterina miniata*	bat star
Muricea fruticosa	brown gorgonian	*Centrostephanus coronatus*	Coronado sea urchin
Stylaster californica	California hydrocoral	*Lytechinus anamesus*	white sea urchin
Diopatra ornata	ornate tube worm	*Pisaster giganteus*	giant spined sea star
Phragmatopoma californica	colonial sand-tube worm	*Pycnopodia helianthoides*	sunflower star
Panulirus interruptus	California spiny lobster	*Strongylocentrotus franciscanus*	red sea urchin
Aplysia californica	California brown sea hare	*Strongylocentrotus purpuratus*	purple sea urchin
Crassedoma giganteus	rock scallop	*Pachythyone rubra*	sea cucumber
Cypraea spadicea	chestnut cowry	*Parastichopus parvimensis*	warty sea cucumber
Haliotis corrugata	pink abalone	*Styela montereyensis*	stalked tunicate
Haliotis fulgens	green abalone	Urocordata	other tunicates
Haliotis rufescens	red abalone	miscellaneous invertebrates	
Haliotis sorenseni	white abalone		
Fishes			
Alloclinus holderi	island kelp fish	*Hypsypops rubicundus*	garibaldi
Coryphopterus nicholsii	blackeye goby	*Lythrypnus dalli*	blue banded goby
Chromis punctipinnus	blacksmith	*Oxyjulis californica*	señorita
Damalichthys vacca	pile perch	*Paralabrax clathratus*	kelp bass
Embiotoca jacksoni	black surfperch	*Sebastes mystinus*	blue rockfish
Embiotoca lateralis	striped surfperch	*Sebastes serranoides*	olive rockfish
Girella nigricans	opaleye	*Sebastes serriceps*	treefish
Halichoeres semicintus	rock wrasse	*Sebastes atrovirens*	kelp rockfish
		Semicossyphus pulcher	sheephead
Environmental features			
Sea temperature			
Substratum			
Water clarity-visibility			

Develop and implement monitoring operations plan

The detailed monitoring protocols for each group of features (kelp forest, sea birds) were documented in peer-reviewed handbooks and published in loose-leaf notebook form to facilitate revisions (Davis and Halvorson, 1988; Table 3). These protocols are available through the park's web site at www.nps.gov/chis. Protocols were reviewed for design performance and updated at ten-year intervals. The first design review was conducted on the kelp forest protocol by an external review panel of statisticians and kelp forest ecologists in 1995.

Table 6. Major public and private collaborators and cooperators in the 'Vital Signs' Monitoring Program in Channel Islands National Park, California.

State of California
California State University
Department of Fish and Game
Regional Water Quality Board
Santa Barbara and Ventura County Air Quality Boards
University of California (Berkeley, Davis, Irvine, Los Angeles, San Diego, Santa Barbara, Santa Cruz)
Private Interests
The Nature Conservancy
Santa Catalina Island Conservancy
Channel Islands Council of Divers
Santa Barbara Museum of Natural History
Santa Barbara Botanic Garden
Tatman Foundation
University of Southern California
Federal Agencies
Department of Agriculture
Forest Service
Man-in-the-Biosphere Program
Department of Commerce
National Oceanic and Atmospheric Administration
National Ocean Service-National Marine Sanctuaries
Fisheries
Department of the Interior
Fish and Wildlife Service
Geological Survey
Minerals Management Service
National Park Service

The review panel affirmed the original design criteria and suggested ways to improve compatibility with other kelp forest studies (Davis *et al.*, 1996a). Statisticians on the panel asserted that a prime directive for such programs should be to maintain the continuity of data collection and to make only minor changes with ample dual sampling to allow comparisons between original techniques and new 'improved' techniques to assure that calibration and correlation are valid. The seabird, rocky intertidal community, terrestrial vegetation, and land bird protocols were also reviewed with similar findings. The Channel Islands National Park 'Vital Signs' Monitoring Program resulted from a collaboration of State, Federal, and private interests (Table 6).

RESULTS: USING MONITORING INFORMATION TO ADDRESS CONSERVATION ISSUES

The Channel Islands National Park 'vital signs' program, begun in 1981, has endured more than 20 years because it proved to be a cost-effective way to reduce uncertainty and increase success of conservation efforts. The program reduced conflicts and provided early warnings of unsustainable conservation practices and invasions by alien species. The early warnings gave resource managers, the public, and politicians time to respond, before remedial actions became too expensive or impossible to enact. The information also provided confidence that actions were actually required. 'Vital signs' information guided ecological restoration by revealing the most successful strategies with timely information otherwise available, e.g., eradication of feral rabbits, rats, and pigs. By documenting success in meeting milestones and by estimating time and costs required for complete eradication, monitoring encouraged persistence, which led to successful eradications.

The information generated by this program significantly reduced uncertainty for management decisions and reduced the costs of resolving serious threats to the park’s ecological integrity. Nevertheless, the monitoring program constituted a relatively large investment in personnel, infrastructure, and operating funds. Conserving the park, while providing for visitor enjoyment and assuring it is left unimpaired for future generations, required a team effort by the entire park staff of approximately 60 people and many partners. Fewer than 12 of these people dedicated full-time to the monitoring program. They were organized into three working groups: one for marine and coastal resources, one for island resources, and one for information management. Change in staff is inevitable in any long-term program, and should be encouraged in order to keep people enthused about their work and willing to grow both professionally and personally. This turnover in staff presented some special problems for maintaining continuity in data collection, archiving, analysis, and reporting because it was difficult to record every significant detail of such a complex endeavor. With at least three people on each work group, there was usually at least one experienced person available to train new staff and to help improve the operation. It was difficult to maintain institutional continuity in field operations and data management with fewer than three people in each work group.

Information management

Information is a primary product of an ecological monitoring program. How the information is managed (communicated, archived, and made available) largely determines a program’s efficacy, reputation for reliability, and image among critics, peers, and advocates. Each of the 14 peer-reviewed monitoring protocols in the Channel Islands National Park program included instructions for data management. In addition to the effort required to collect and record monitoring information, 35-40% of the monitoring program’s fiscal and human resources were spent on storing, communicating, and making available the information collected and produced by the ‘vital signs’ program (Dye, 2002). More academic or theoretical estimates that information management should consume only 10-15 % of the resources of an ecological monitoring program have underestimated seriously the effort required in practice (Royal Society of Canada, 1995).

Other practical information management lessons learned during development of the Channel Islands ‘Vital Signs’ Program include: 1) use standard, commercially available, software, i.e., avoid custom programs; 2) specify common fields for all records that relate all databases, e.g., date and location; and 3) plan for and embrace change. Not only are ecosystems dynamic, engineered systems used to manage information are also dynamic. The Channel Islands program experienced 10 generations of software and operating systems in its the first 16 years. It evolved from Apple II microcomputers to Windows-XP and UNIX environments. To describe long-term trends in ecosystem ‘vital signs’ and to determine normal variation in vital sign parameters, data collected at the beginning of the program had to be compatible and comparable with data collected and stored during the middle and the end of the program. This meant that every time a computer operating system changed or the database software changed, the entire database had to be converted to a new system. These technological changes were inevitable, so the program was designed to maintain information continuity and compatibility by focusing on program goals, not on means of achieving the goals.

Annual reports for each monitoring protocol, e.g., kelp forest or island birds, described current resource conditions, archived annual data, documented monitoring activities that varied from year to year, provided an end-point for otherwise endless monitoring activities, and documented changes in monitoring protocols. The annual reports were also emotionally important for the monitoring staff, and provided opportunities to market the program and its accomplishments among the funding agencies, academia, and the general public. In addition to annual reports, formal peer-reviews of protocols, operations, and results at 10-year intervals helped to assure program vitality and relevance. During protocol reviews, expert scientists re-examined design criteria for accuracy and precision, analyzed data for power to resolve changes in resource conditions, and recommended protocol revisions. This process provided a formal history of program evolution that helped assure data continuity while employing modern technologies and methodologies.

Examples of How Monitoring Helped Resolve Environmental Issues

At the California Channel Islands, 'vital signs' monitoring helped to control and eliminate invasive alien species, to detect and mitigate pollution, to recognize and demonstrate unsustainable uses, to change fishery management strategies, and to develop and evaluate population and ecosystem restoration methodologies. A few specific examples are described below.

Invasive alien species constituted an ever-increasing threat to the park. Stewards of the California Channel Islands have used the monitoring program to direct and evaluate removal of several alien species, including burros on San Miguel Island, European hares on Santa Barbara Island, feral pigs on Santa Rosa Island, and South African iceplant on Anacapa Island. Before instituting monitoring programs, eradication efforts were sporadic and ineffective. Numerous efforts were made to remove feral rabbits from Santa Barbara Island in the 1950s and 1960s by hunting and spreading poison bait on the island (Sumner, 1959). None were successful until the 'vital signs' program provided specific information about the effectiveness of various population control methods (trapping vs. hunting), rabbit population trends, and reliable cost and time estimates for complete eradication. By reducing the uncertainly of success through monitoring, the eradication program gained enough support to sustain the effort long enough to succeed. In marine ecosystems, three invasive alien algal species have been detected in or near the park: *Sargassum muticum*, *Undaria pinnatifida,* and *Caulerpa taxifolia.* These species do not appear to have impacted park ecosystems yet, but have potential to do so quickly and significantly.

Even before the 'vital signs' program began, long-term wildlife population monitoring in the park provided an early warning of regional pollution with global consequences. Monitoring reproduction and recruitment in California brown pelican rookeries on Anacapa Island identified pesticide (DDT) pollution in the Southern California Bight, and provided sufficient time to ban DDT and restore pelican productivity before the population was extirpated (Anderson and Gress, 1983). Today the park's 'vital signs' program indicates that DDT is still clearly a problem in coastal ecosystems as evidenced in continuing reproductive difficulties experienced by peregrine falcons and bald eagles (Detrich and Garcelon, 1986). The 'vital signs' program indicated that progress was being made, which in turn encouraged society to continue supporting abatement activities.

Nearby Cabrillo National Monument, in San Diego, California (300 km south of the park) provided another example of how 'vital signs' monitoring informed controversial conservation decisions, such as when human intervention in park ecosystem dynamics was appropriate. The Channel Islands National Park rocky intertidal monitoring protocol was modified and applied to the Monument's tide pools in 1989 (Engle and Davis, 2000a). In 1992, the San Diego City municipal sewage treatment effluent discharge pipe ruptured, erupting 16 billion gallons of treated effluent into the sea over a two month period less than a kilometre from the monument's monitored tide pools. Many people were rightfully concerned about marine life in the tide pools and adjacent kelp forests (Tegner *et al*., 1995). Objective information from pre-spill monitoring established clearly that the effluent had no immediate negative effect on the 15 'vital signs' taxa monitored (Engle and Davis, 2000b). Closing the tide pool area to visitors during those two months in order to protect them from potential health hazards in the effluent reduced trampling and other visitor-related disturbances. The consequences were increased abundances of most 'vital sign' taxa.

The 'vital signs' program in this case saved unnecessary litigation that often occurs in such situations when people believe, in the absence of knowledge, that damage is self-evident. The two-month closure associated with the effluent spill constituted a large environmental experiment unlikely to be conducted intentionally.

Since the ‘vital signs’ program was in place, it was possible to measure the effects of the event and to separate the longer-term trends in populations associated with regional environmental events, such as El Niño. For example, a chronic loss of California mussels, *Mytilus californicus*, and feather boa kelp, *Egregia menzesii*, recorded for three years before the effluent spill, continued at the same rate during and after the spill. While ground cover of ephemeral algae and sea grass, *Phyllospadix* sp., increased significantly during the same events (Engle and Davis, 2000b).

Frequent and extensive analysis and synthesis of monitoring data facilitated discovery of new features and characteristics of park ecosystems. Outbreaks of fatal new diseases, such as withering syndrome in black abalone, *Haliotis cracherodii*, were previously unknown, in part because no rigorous ecological monitoring took place before the ‘vital signs’ program. Monitoring revealed not only that black abalone populations collapsed in the park, but also provided a regional geographic and multi-year temporal description of the spread of catastrophic mortality (Richards and Davis 1993). Monitoring characterized population size structure of surviving abalone, showing persistence of large individuals at some sites but not at others. This information exonerated fishing (that took only large abalone) as a proximal cause of the population collapses at some islands, but implicated fishing as a contributing stress at others. Monitoring also showed that adult black abalone populations ceased to reproduce successfully when densities fell below 50% of their original values. These quantitative descriptions directed subsequent research to examine potential infectious agents, rather than toxic pollutants or poaching and other human activities, and led to the discovery of a new species of pathogen (Friedman *et al.,* 1995). ‘Vital signs’ monitoring provided an early warning with sufficient information to protect disease-resistant individuals from fishery harvest and thereby help ensure survival of another generation.

In the latter 20th Century, many fisheries were managed and evaluated largely on the basis of fishery-dependent landings data that did not accurately reflect changes in fished populations (Schroeder *et al*., 2001). Fishery-independent monitoring provided essential corroborative information for fishery managers (Botsford *et al.,* 1997). Ambiguous fishery landings data obscured the catastrophic serial depletion of five species of abalone (*Haliotis* spp.) and a sea urchin (*Strongylocentrotus franciscanus*) that supported a commercial diving fleet in southern California before monitoring data were available (Dugan and Davis, 1993; State of California, 1995; Davis, 1998). As a result, fishing exhausted abalone populations before fishery management policies could be changed, and drove at least one species to the verge of extinction, *Haliotis sorenseni*, as evidenced by its listing as the first endangered marine invertebrate in the United States (Davis *et al.,* 1996b, 1998; Davis, 2000; Hobday *et al.,* 2001). Early warnings of population collapses and ecosystem shifts that were generated by ‘vital signs’ monitoring prompted changes in resource management policy and strategy. These changes included explorations of new placed-based conservation paradigms, i.e., marine reserves, by the State legislature in a Marine Life Protection Act (Chap. 10.5 California Fish and Game Code, Sections 2850 and 2863) and by the State Fish and Game Commission in establishment of a large network of marine reserves in park waters (PISCO, 2002; Davis, in press).

Political systems are frequently frozen into inaction by uncertainty (Wurman, 1990). Reliable fishery independent data from ‘vital signs’ monitoring allowed political processes to work by reducing uncertainty regarding abalone population status. Abalone population status could only be inferred from declining fishery landings, and those trends were persistently contested by fishing interests. Only after ‘vital signs’ monitoring data confirmed imminent abalone population collapses did the California Fish and Game Commission and State Legislature eventually close five abalone fisheries to prevent loss of critical brood stock, to facilitate recovery, and to reduce the costs of rebuilding depleted populations statewide. ‘Vital signs’ methodologies were also used to test a variety of different abalone population restoration techniques at the California Channel Islands (Davis, 1995, 2000; Davis and Haaker, 1995).

DISCUSSION

The Channel Islands National Park 'Vital Signs' Monitoring Program became a prototype for many other national parks as well as other agencies, and it helped to catalyze a national 'vital signs' program for the U.S. National Park System (National Park Service, 1995; Stanton et al., 1999). The step-down planning process described here has been used successfully in a wide variety of ecological settings with many Delphi-experts, including deserts (Organ Pipe Cactus National Park and Lake Mead National Recreation Area), mountains (Great Basin, Lassen Volcanic and North Cascades National Parks), and the New England coast (Acadia National Park). Other parks emulating the Channel Islands model include Virgin Islands (USVI), Dry Tortugas (FL), Denali (AK), Great Smokey Mountains (TN-NC), Shenandoah (VA), Olympic (WA), a cluster of small prairie parks in the mid-west, and a cluster of parks on the Colorado Plateau. Based on the experience gained in prototype park programs, the National Park Service is currently implementing 'vital signs' programs in 270 units of the National Park System.

Sustained time-series data at landscape scales produced by 'vital signs' programs permit resolution of complex environmental issues too difficult to address with typical ecological studies focused on metre-square plots for one or two seasons (Likens *et al.,* 1977; Tilman, 1989; Halvorson and Davis, 1996; Baskin, 1997). Separating effects of El Niño events, pollution, and fishing on coastal ecosystems at the Channel Islands required regional (100s km) analysis over several decades. This kind of analysis was needed to achieve the levels of certainty required to guide meaningful political actions to avoid irreversible resource damage while sustaining economic development and exploitation of fishery resources. Monitoring data also allowed research statisticians to explore previously unavailable real-world information they used to develop new analytical methodologies.

Monitoring practitioners should publish both positive results and negative efforts. It is important to document both techniques and designs that worked, and those that did not, in peer-reviewed literature and in topical symposia so others can avoid the same mistakes. Ecological monitoring is no longer simply a compliance-mandated record of environmental parameters. Today it drives explorations at the edge of conservation biology and ecology. As such, its discoveries need to be documented, critiqued and discussed widely. Such programs also need to produce models of excellence to create and sustain effective 'vital signs' monitoring networks to inform and guide conservation.

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